SALMON, LENIN EDUARDO. Photic Stimulation, Selective Attention, and Averaged Evoked Responses in Humans. (1971)
Directed by: Dr. M. Russell Harter. Pp. 61.

The present study was an attempt to investigate the differential effects of attention upon visually evoked cortical responses (VERs) when preparatory states and peripheral influences are reduced to a minimum. Four subjects were presented a random series of relevant and irrelevant light flashes and were instructed to count the number of relevant signals (count condition) or to make a key release every time the attended stimulus was presented (reaction time condition). Stimuli were presented at a constant rate of 520 msec. (fast rate), or 1030 msec. (slow rate). Subjects were instructed to fixate a central reference point on the projection screen throughout the length of the trial. Similarly, they were asked to withhold any response not related to the task.

Averaged VERs from the occipital cortical region showed a consistent increase in amplitude at latencies of 220-250 msec. and 290-340 msec. when the stimulus was relevant, as compared to VERs to the same stimulus when it was irrelevant. It was also found that neither response conditions nor rate of presentation had a significant effect on the cortical response.

These results were discussed in terms of the selective attention hypothesis and the differential preparatory states

position, and two general conclusions were drawn. First, attention to a particular stimulus enhances the cortical response it evokes, especially a positive-going deflection occurring at or around 300 msec. Second, this enhancement is not produced by the subject's anticipation of the presentation of the relevant signal, at least in experiments in which its presentation is made random.

PHOTIC STIMULATION, SELECTIVE ATTENTION, AND AVERAGED EVOKED RESPONSES IN HUMANS

by

Lenin E. Salmon

A Thesis Submitted to
the Faculty of the Graduate School at
The University of North Carolina at Greensboro
in Partial Fulfillment
of the Requirements for the Degree
Master of Arts

Greensboro
1971

Approved by

M. Russell Harter

Thesis Adviser

APPROVAL PAGE

This thesis has been approved by the following committee of the Faculty of the Graduate School at The University of North Carolina at Greensboro.

Thesis Adviser M. Russell Harter

Committee Members O. R. Soderquist

Robert G. Eaves

May 21, 1971
Date of Approval

ACKNOWLEDGMENTS

The author wishes to extend his appreciation to Dr. Robert G. Eason and Dr. David R. Soderquist for serving as members of the Thesis Committee.

Special gratitude is offered to Dr. M. Russell Harter, the Thesis Adviser, for his dedicated guidance and invaluable criticisms throughout the preparation of this work.

Sincere thanks for their complete cooperation as subjects are expressed to Miss Sharon Y.Y. Shan, Miss Lynda E. Wilson, Mr. Stephen R. Harris, and Mr. William H. Seiple.

This work was partially supported by Grant GB-8053 from the National Science Foundation.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Introduction

The past decade has provided experimental psychology with innumerable advances in electrophysiology, particularly work related to cortical responses to photic stimulation. A major reason for such advances has been the use of averaging computers for the detection and summation of visually evoked responses (VERs). These responses are time-locked to the stimuli that elicit them, and under most conditions have a maximal amplitude of about 15 μV, measured between the most positive and most negative points (Jonkman, 1967).

The spontaneous electrical activity of the brain when the subject (S) is in a relaxed state ranges from 20 to 150 μV, and is independent of the photic stimulus. This background activity is confounded with the VERs, but since it is not time-locked to the onset of the stimulus, it tends to cancel out as the number of computer summations grows larger. On the other hand, the VERs, which are assumed to be identical for a given stimulus (Cigánek, 1969), increase in amplitude when summated as a linear function of the number of stimulus presentations (Jonkman, 1967).

The final product is an averaged evoked potential relatively free of background "noise" which can be printed out on graph paper by an X-Y recorder, or in digital form in reference to a baseline of zero. These records constitute the raw

data used by most investigators in the field today. Visually evoked responses can be recorded from most cortical areas, but they are usually larger when recorded over the primary (occipital) region (Groves & Eason, 1967) than when they are obtained simultaneously from the frontal, parietal, or temporal sections.

Influences of the Organism on VERs

As discussed below, the evoked cortical activity is not only a response to the intrinsic characteristics of the stimulus (intensity, color, pattern, size, etc.), but also a reflection of the state of the organism at the moment of stimulation. The same physical stimulus has been shown to evoke different responses from the same S depending on whether he is aroused, relaxed, fatigued, drowsy, attentive, distracted, vigilant, etc.

Many investigators have manipulated these variables, especially arousal and attention, in an effort to understand their effects on the VER; that is, how the induced state of the organism can modify its response to a physically unchanging stimulus. Unfortunately, the variety of results obtained in these studies has offered grounds for controversial interpretations which have not yet been settled.

It has been reported, for instance, that attending to a particular stimulus produces an increase in the amplitude of the evoked response, especially when the level of arousal is high, whereas the same stimulus evokes a smaller response

when attention is directed away from it, particularly when the level of arousal is low (Davis, 1964; Donchin & Cohen, 1967; Eason, Harter, & White, 1969; García-Austt, Bogacz, & Venzulli, 1961, 1964; Gross, Begleiter, Tolsin, & Kissin, 1965; Haider, Spong, & Lindsley, 1964; Jane, Smirnov, & Jasper, 1962; Kopell, Wittner, & Warrick, 1969; Satterfield, 1965; Spong, Haider, & Lindsley, 1965; Sutton, Braren, & Zubin, 1965a; Wilkinson & Morlock, 1967, and others).

Data suggesting that just the opposite might be the case (i.e., a decrease in the amplitude of the cortical response is observed when S is attending to the source of stimulation) have also been reported (Bergamini, Bergamasco, & Mombelli, 1966a, 1966b; Melzack & Burns, 1965; Mombelli, Bergamini, & Bergamasco, 1964; Naquet, Fernández-Guardiola, Fisher-Williams, & Régis, 1960; Shaw & Thompson, 1964a, 1964b; Thompson & Shaw, 1965, among others). A third position has been strongly supported by Näätänen (1967, 1969a, 1969b, 1970), emphasizing that the differences found between responses to attended and non-attended stimuli are not a product of selective attention but a result of differential preparatory states of the organism to these two kinds of stimulation.

These three conclusions are, at least on the surface, incompatible with one another. The nature of their differences lies in the interpretation of the neurophysiological processes underlying the state of the organism at the moment of stimulation, and the manner in which the underlying processes influence the evoked response.

A common starting point, however, is the activation and attention theory postulated by Lindsley (1957), which states that the reticular formation of the midbrain acts upon the cortex in two separate ways: Its rostral portion activates the cortex via the extrathalamic ascending reticular activating system (ARAS), thereby producing a state of non-specific general arousal. A more specific alerting function is subserved by the thalamic extension of the reticular formation, better known as the diffuse thalamic projection system (DTPS), which reaches the cortex via the anteroventral, ventromedial, intralaminar, and reticular nuclei of the thalamus (Lindsley, 1957; Moruzzi & Magoun, 1949).

The ARAS as an Inhibitor of VERs to Attended Stimuli

In a study reported by Naquet, et al. (1960), electrical stimulation of the ARAS in cats produced an enhancement of the VER at the subcortical level, but when recorded from the cortex this same stimulation produced desynchronization of the electroencephalographic (EEG) activity and a decrement in the evoked response. The enhancement of the response below the cortex has been interpreted as being caused by an increase in pupillary diameter due to the electrical stimulation, thereby allowing more light to hit the retina (Fernandez-Guardiola, Harmony, & Roldan, 1964).

Similar results were found in studies with human Ss by Mombelli, et al. (1964), and later by Bergamini, et al.

(1966a, 1966b). In their experiments pupillary size was kept constant by atropinization. Their data showed a correlation between decreasing VER amplitude and increasing EEG desynchronization. Furthermore, it was found that states of distraction, attention, and arousal resulted in a decrement in VER amplitude.

Thompson & Shaw (1965) suggested that the amplitude of the cortical evoked response from association areas in cats was negatively correlated with the level of behavioral attention and arousal. Their position was that excitation of the ARAS and DTPS during states of arousal and attention produced a desynchronization of the ongoing cortical activity which in turn attenuated the amplitude of the VER. Their position, of course, is analogous to that expressed earlier by Mombelli, et al. (1964) and Bergamini, et al. (1966a, 1966b), and will be compared to data presented by investigators who believe attention produces an enhancement of the evoked response.

The ARAS as a Facilitator of VERs to Attended Stimuli

Eason, et al. (1969) manipulated both arousal and attention in humans using the following procedure. Subjects were to react to concomitant, although never simultaneous, flashes of light appearing in one (left or right) visual field while ignoring irrelevant signals presented in the other. This task was performed under threat of shock and under no threat of shock.

Occipital recordings showed that the relevant or attended flashes evoked a significantly larger response than the non-attended stimulus. Similarly, VERs obtained under threat of shock were larger in amplitude than those recorded under no threat of shock for both relevant and irrelevant stimuli. Attenuation of VERs to non-attended stimuli was interpreted as being caused by an "active inhibitory neural process" which seemed to act as a selective filter triggered by the attentive state of S. Although these findings clearly contradict those of Thompson & Shaw's, no conclusive comparisons between these two outcomes can be made because of the differences in species and recording sites used.

That recording site is of critical importance was demonstrated by the results obtained by Thompson, Denny, & Smith (1966) and by Groves & Eason (1967). Thompson, et al. recorded VERs from the occipital area in cats upon electrical stimulation of the frontal cortex. They found an increment in amplitude over the primary area, while simultaneous records obtained from the association area showed a reduction in amplitude. These results are more consistent with the occipital recordings obtained by Eason, et al. (1969), particularly because the state of cortical activation produced by the electrical shock did result in an enhancement of VER amplitude.

Haider, et al. (1964) reported that a reduction in attention during signal detection in a vigilance task was

directly related to a decrease in amplitude and an increase in latency of the VER. In their experiment, Ss had to detect dim (signal) flashes interspersed among slightly brighter non-signal flashes. They found that occipital responses to non-signal stimuli decreased with a decrease in detection of the relevant signals, thus suggesting that VER amplitude correlated positively with performance over time. Furthermore, VERs to signal stimuli were larger when the flashes were detected than when Ss failed to do so, these differences being independent of the decline of vigilance over time. Although it was not investigated, the implication of these results was that VERs increase in amplitude when attention is high.

Attention, as determined by task difficulty, was reported by Davis (1964) as responsible for amplitude enhancement of cortical potentials. His Ss were asked to judge whether a given tone in a series was slightly (3 dB) louder than the preceding one. Results showed that responses evoked by this signal were significantly larger when a decision had to be made than when Ss had to respond without making a judgement. Similarly, Gross, et al. (1964) demonstrated that cortical potentials to clicks were enhanced when S's attention was shifted from a reading situation to a condition in which he actually had to count the clicks being presented.

In a replication of the study performed by Haider, et al. (1964), Ritter & Vaughan (1969) reported an enhancement of cortical responses to signal stimuli detected by Ss.

This increase was particularly pronounced in a late positive component (LPC) ranging in latency from 300 to 350 msec. in both occipital and vertex recordings. The absence of such a component in Haider, et al.'s study was attributed to the bipolar linkage of the electrodes, which tended to obscure such potentials.

Ritter and Vaughan also reported an LPC enhancement in cortical responses to auditory signals detected by S, although in this case its latency was longer (450-550 msec.). It was suggested that the reason why Davis (1964) did not report such an LPC increment in his auditory discrimination task was his restriction in sampling time (375 msec.) after onset of stimulus. Similar changes in LPC amplitude as a function of task-relevant information provided by the stimulus had previously been reported by Sutton, et al. (1965a), Cohen & Walter (1966), and Donchin & Cohen (1967).

The study by Donchin and Cohen was designed to test the conclusions drawn by Horn (1960) that stimulus relevance was not responsible for the differences in VER amplitude. In his experiment with cats, VERs to flashes were larger in amplitude when the S was in a resting state than when the S was induced to a visual search by presenting a mouse in the cage, with all non-visual stimuli from the mouse blocked by a special screen. Horn concluded that the attenuation of evoked responses was due to visual search per se, independent of the significance of the stimulus to the S. Similarly,

he suggested that the peripheral gating mechanism proposed by Hernandez-Peon, which facilitates inputs from a sense modality when it is attended while simultaneously inhibiting impulses from a non-attended modality (Hernández-Peón, Scherrer, & Jouvet, 1956), could not account for the VER differences obtained, since both stimuli were presented within the visual modality.

Donchin and Cohen agreed with Horn's rejection of the gating hypothesis, whose inadequacies were further pointed out by Marsh, Worden, & Hicks (1962). They contended, however, that should visual search per se be truly responsible for the differences between cortical responses to attended and non-attended stimuli, then VERs to a flash searched for should be no different from VERs to this same signal when S is searching for another visual stimulus. Any discrepancy in VER amplitude would indicate, then, that experimental variables, such as significance of the stimulus, and not visual search, are responsible for the variation.

In one condition they presented Ss with brief flashes at irregular (2-3 sec.) intervals, projected on a Necker cube drawn on a white card. Their task was to count either the number of flashes while ignoring the figure (flash condition, FC) or to count the number of figure reversals (reversal condition, RC) and ignore the flashes. All were told to press a switch every tenth count. Occipital recordings showed that responses to the flash were larger during the FC

than during the RC; that is, VERs to the stimulus searched for were not attenuated (FC), rather, the decrease was observed when Ss searched for some other visual stimulus (RC).

Similar results were obtained in another condition in which the background was an actual alternation of two figures and Ss had to press a reaction time (RT) key every time one of the figures was replaced by the other (RC). Occipital responses to the figures were larger during RC and vice versa, thus providing more support to the postulation of selective attention as the reason for VER amplitude increment. A replication of this study by Kopell, et al. (1969) yielded similar results, although attention did not have as much influence on the RC as it did on the FC.

Perhaps the broadest conclusion that could be drawn from the studies reviewed heretofore is that all of them, either implicitely or explicitely, suggest the existence of a neural mechanism which facilitates the perception of stimuli that S wishes to attend to, and simultaneously somehow attenuates the input from stimuli which bear no relevance for the particular situation.

The ARAS, the Slow Negative Potentials, and the VERs

The conclusion stated above is in line with the postulate concerning the transient activating processes generated by the DTPS (Lindsley, 1960; Morgan, 1965). A new line of thought, however, has developed during recent years. Its proponents do not emphasize selective attention and its

underlying processes as the modifiers of evoked potentials to relevant stimuli; rather, they seriously question their effects and suggest other channels that may be performing these facilitatory functions, namely slow negative shifts in anticipation of relevant stimuli.

These "readiness potentials" (Kornhüber & Deecke, 1965), "motor potentials" (Gilden, Vaughan, & Costa, 1966; Vaughan, Costa, & Ritter, 1968; Vaughan, Costa, Gilden, & Schimmel, 1965), "expectancy waves" (E-waves) (Walter, 1964b), or "contingent negative variations" (CNV) (Walter, Cooper, Aldridge, McCallum, & Winter, 1964c) have been defined as indicants of S's expectancy of a relevant stimulus (S_2) after a warning signal (S_1) has been paired with it, thus indicating preparation set and cortical "priming" (Walter, 1964b) or excitability. This position has been supported by studies showing a high degree of correlation between CNV and cortical excitability (McAdam, 1969) and attentiveness-alertness (Low, Coats, Rettig, & McSherry, 1967). The Low, et al. study also reported CNV as having no consistent relation with anxiety, as had been previously suggested by Walter (1965).

That CNV is related to attention and RT was suggested by Tecce & Scheff (1969). They presented distractors (numbers or letters) before and within the S_1-S_2 interval, and found that CNV amplitude decreased and RT increased when S had to recall the distracting stimuli after their response to S_2. This discrepancy was more pronounced when the distractors to

be recalled were those presented within the interval. In a later study (1971) Tecce reported that CNV and attention were positively and monotonically associated, while CNV and arousal level correlated non-monotonically (inverted-U relationship).

The results of CNV studies reviewed so far led to the conclusion that this negative direct-current (DC) potential is present in all attentiveness-alertness situations. The implication concerning the specific relationship between CNV and the response to a relevant stimulus will be investigated in the following paragraphs, within a discussion of the work of one of its major proponents: Risto Näätänen.

Näätänen (1967, 1969a, 1969b, 1970) has postulated that the amplitude increase observed in cortical responses to attended stimuli is not the product of the action of a neurological mechanism that facilitates the perception of relevant stimuli while at the same time attenuates that of the irrelevant one. Rather, he suggested that the non-specific cortical activation induced by the ARAS during attentive states influences evoked potentials from all sensory modalities, independent of the direction of attention, thereby making enhancement of responses to relevant stimuli a non-specific phenomenon. He further has pointed out that during attention the entire cortex is activated, and all evoked responses are enhanced, regardless of stimulus significance or relevance.

Evoked potentials to relevant stimuli are enhanced and those for physically equivalent irrelevant signals are not "probably not because of a selective filtering or blocking of sensory impulses but systematic differences in cortical activation between the moments of presentation of the relevant and irrelevant stimuli" (Näätänen, 1970, pp. 179-180). This activity was thought to be higher at, and immediately prior to, the moment of presentation of the relevant stimulus than for the irrelevant one, probably due to regularity in stimulus presentation.

Näätänen supported his first suggestion (i.e., responses to irrelevant stimuli are not attenuated during attentive states) by showing that evoked potentials produced by irrelevant clicks presented within the S_1-S_2 interval were enhanced, as compared to irrelevant clicks presented outside this interval (Näätänen, 1967, first experiment). However, this evidence cannot be accepted entirely since it was probable that the "inside" clicks themselves, and not the S_1, could have been used as warning signals by Ss, as they always occurred prior to the presentation of the S_2. If true, then, the clicks acquired relevance, resulting in an increase of their cortical response, yielding supportive evidence against Naatanen's hypothesis.

A good control for this possibility would have been a condition in which no inside clicks were presented, and a comparison of evoked potentials to the S_1 in both conditions.

If responses to S_1 decrease when the clicks are presented, it may indicate that the clicks have become relevant and are serving as warning signals instead of the first flash.

Näätänen's second experiment (1967) was designed to demonstrate his second hypothesis that responses to relevant and irrelevant stimuli differ because S can predict the time of presentation of the relevant stimuli, and thus be prepared for them. In this study clicks and flashes were randomly presented at irregular time intervals. The stimuli in the irrelevant modality were kept constant, while S had to press a key whenever a weaker stimulus was presented in the relevant modality. No significant differences were found between relevant and irrelevant clicks, and he interpreted this result as supporting his hypothesis (the Null Hypothesis) that stimulus relevance has no influence on the evoked response when S cannot predict if and when a relevant stimulus will be presented. Responses to relevant flashes, however, did show a significant increase, especially in the LPC, over those to irrelevant flashes. This difference was interpreted as being caused by better control of peripheral factors (fixation, eye movements, etc.) when the flashes were relevant than when they were irrelevant.

This same hypothesis was tested in another way in Näätänen's third experiment (1967). If S knew when a relevant stimulus would be presented, he would be more prepared to make the necessary response, therefore the cortical

response to such a stimulus should be larger than that for a stimulus which required no response, and consequently no preparation. He used the auditory modality, since peripheral factors are easier to control in audition than in vision. Weak and strong clicks were presented alternately at one-second intervals, thus allowing S to know which kind of stimulus would be presented next, and approximately when. When strong clicks were relevant, S had to detect louder clicks interspersed among them; when weak clicks were relevant they had to detect even weaker clicks.

The hypothesis that knowing when the relevant stimulus will come produces an enhancement of the cortical response to that stimulus was supported by the significant differences obtained between relevant and irrelevant weak clicks. The non-significant differences found between relevant and irrelevant strong clicks, however, were interpreted as being a result of S's finding the task too easy (probably due to the loudness of the clicks), therefore making it unnecessary for him to use cues for performance improvement during the relevant condition.

Karlin (1970) reported a conflict between the interpretations of the findings from Näätänen's second and third experiments. Clicks in the former were comparable to the strong clicks of the third experiment, and the results from both studies were similar (non-significance between cortical potentials to relevant and irrelevant clicks). Elimination

of cues for differential preparation, however, were attributed to be the reason for the former, and failure to use these same cues because of subjective easiness of the task for the latter.

These inconsistencies were of no great help in settling the conflict of opinions as to which process is responsible for the amplitude enhancement in cortical potentials evoked by a relevant stimulus. On the contrary, a heated argument concerning these two positions seems to have developed between Näätänen and Donchin and Cohen, as a result of their 1967 experiment reported above.

Näätänen claimed (1969a, 1969b) that the different results for attended and non-attended stimuli reported by Donchin and Cohen were not a product of a selective attention process, but were a product of S's differential preparation for the irrelevant and relevant stimuli. Since, for instance, the inter-flash intervals were fairly constant (2-3 sec.), S could predict with approximate accuracy when the next flash would appear. It was possible, then, that S could attend to the flash, relax during the interval (when the figure reversals were presented), and resume alertness for the next flash. The same rationale can be applied to the reversal condition. Similar criticisms have been offered by Karlin (1970).

Donchin & Cohen (1969a, 1969b) argued that Näätänen's interpretation of their data was not a disputation of their

findings, although they conceded that CNV could be related to LPC enhancement (Cohen & Walter, 1966; Donchin & Smith, 1968). Näätänen, however, insisted that the only way to be absolutely confident that the differences between relevant and irrelevant stimuli, if found, were a reflection of selectiveness of attention, was "to deliver the relevant and irrelevant stimuli in such a manner that S cannot anticipate the delivery of the relevant stimuli but has to be continuosly alert throughout the experimental series" (Näätänen, 1969a, pp. 644). However, the results from the experiment designed to test this very fact (Näätänen, 1967, second experiment) were contradictory for the two modalities tested.

Summary and Conclusions

In reviewing the findings provided by the three positions discussed in this section, it can be generally concluded that attention directed to a stimulus does provoke an enhancement of the cortical response. The position that attention causes a decrease in the evoked potential cannot be taken as having been conclusively demonstrated at least for two reasons: first, attention, stimulus significance, and evoked potential enhancement appear to be closely related (Donchin & Cohen, 1966; Ritter & Vaughan, 1969; Sutton, et al, 1965a, and others). This is difficult to account for in animal experiments because it is hard, if at all possible, to assess the degree of interest or significance, and attention for that matter, that an animal assigns to the relevant

stimulus. Second, in human studies the decrease of response amplitude to attended stimuli has been obtained under atropinization of the pupil. There is evidence (Hess & Polt, 1960) that pupil size is related to the interest value of the visual stimulus. If the relation between information value, attention, and cortical response is true, then by keeping the pupil rigid the critical influences of this variable are eliminated. Furthermore, the vast amount of evidence in support of the facilitatory functions of attention strongly suggests that indeed this may be the case.

Another controversy arises when the causes for this amplitude enhancement during attentive states are investigated. Is this increase a product of the selective attentiveness of S to a particular stimulus, or is it due to nonspecific changes in arousal resulting from S's anticipation of such relevant stimulus due to predictability of its presentation? Donchin and Cohen, and Näätänen, stand at opposite poles of this conflict.

It seemed that the only way to attempt to find some degree of compatibility between these two extreme positions was to design a selective attention experiment in which the two most crucial factors specified by Näätänen (1969a), namely differential preparatory states and peripheral influences, could be eliminated.

Purpose of Present Experiment

The study reported in this thesis attempted to account for these and other variables in several ways: (a) by presenting both relevant and irrelevant stimuli within a single modality (visual), thus eliminating the possibility of gross orienting responses toward the relevant modality (e.g., S's concern about accommodation of earphones when clicks are relevant, at the expense of losing visual focusing due to movement); (b) by presenting the stimuli to approximately the same retinal area, and instructing S to maintain fixation on a common reference point throughout the length of the trial, thereby avoiding variation caused by stimulation of different retinal areas (as may have been the case in Donchin & Cohen's study, since they did not use fixation points); (c) by using stimuli of approximately the same size and duration, thus avoiding the possibility of one being more difficult to detect than the other; (d) by randomizing the presentation of relevant and irrelevant flashes, thus making it impossible for S to correctly predict the next stimulus presentation; and (e) by presenting stimuli at exactly the same time interval so preparatory states, if any, would be equally present at the moment of presentation of every stimulus, regardless of significance.

By using this procedure, any differences obtained between cortical responses to relevant and irrelevant signals may be attributed to S's selective attention to the relevant

stimulus and not to non-specific changes in arousal. The responses to the relevant stimulus should be larger in amplitude, especially in the LPC, than those to the irrelevant flashes. Another purpose of this study was to investigate whether the effects of selective attention would vary as a function of the rate of stimulus presentation and the nature of the response required of Ss.

Method

Subjects

Data presented in this report were obtained from two male and two female graduate students, ranging in age from 22 to 30 years. Three of them had previous experience in similar kinds of electrophysiological experiments.

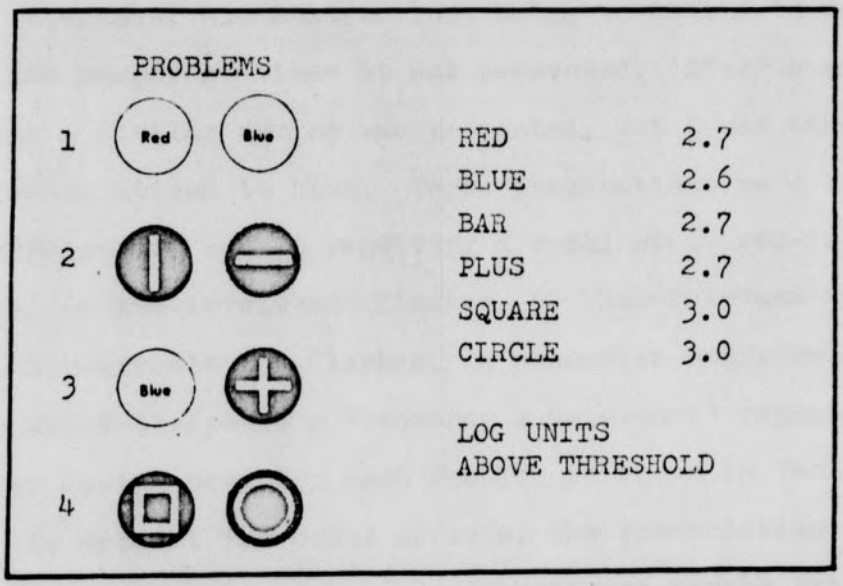
Experimental Design

Frequency (rate) of presentation and manner of responding, each having two levels, were manipulated across each of four problems (Table 1) which consisted of a relevant flash S had to respond to, and an irrelevant flash S was instructed to ignore. Each problem required discrimination between two randomly presented stimuli: red and blue colors (Problem One); vertical and horizontal bars (Problem Two); a blue color and crossed bars (Problem Three); and a circle and square figures (Problem Four).

The two responses required of Ss (counting the relevant flashes or making an RT key release) and the two rates of presentation (520 msec. for the fast frequency and 1030

TABLE 1

A Graphic Representation of the Stimuli



Note.—Log units above threshold were measured by No. 96 Wratten neutral density filters.

for the slow frequency) generated four experimental conditions (counting and RT at slow and fast frequencies) for each Problem. Within each condition, both members of the Problem were made relevant in an ABBA fashion to counterbalance for the effects of time. For instance, under one condition (e.g., counting at slow rate of presentation), S was randomly presented 32 red and 32 blue flashes at 1030 msec. intervals, his instructions being to attend to red and count the number of times it was presented. After a rest interval a similar series was presented, but S was then instructed to attend to blue. These instructions were then counterbalanced, each S receiving a total of 64 red-relevant flashes, 64 red-irrelevant flashes, 64 blue-relevant flashes and 64 blue-irrelevant flashes. A schematic representation of the 2x2x2 (Response x Frequency x Relevance) repeated measures design used for each Problem is shown in Table 2.

To account for order effects, the presentation of the experimental conditions was counterbalanced across Problems for four replications by means of a 4x4 Graeco-Latin Square (Kirk, 1969). Each replication required two 90-minute recording sessions, Problems being varied across sessions.

Apparatus and Recording Technique

The stimuli were generated by a Lehigh Valley Electronics (LVE) 1346 Multi Stimulus Projector. The display was circular in shape, measuring 28 mm. in diameter, and subtended a visual angle of 2.46°. It was surrounded by a

TABLE 2

Design Used for Problem One

Relevance	RED and BLUE			
Frequency	520		1030	
Response	Ct.	RT	Ct.	RT
S1	1	2	3	4
S2	2	4	1	3
S3	3	1	4	2
S4	4	3	2	1

Note.—Numbers indicate order of rate of presentation and response conditions. Stimuli (red vs. blue) within each condition were attended in an ABBA sequence.

piece of white cardboard measuring 2'x3'. The illumination of the display (except during stimulus presentation) and surround was 0.10 and 0.65 mL respectively. Stimulus duration was 40 msec. with stimulus rise and fall time of approximately 40 msec. (as measured by a photocell).

Subjects were comfortably seated in an Ophtalmologist's chair, which could be raised or lowered so that S's line of vision were horizontal to the stimulus display located 65 cm. away. Subjects fixated a small dot centered in the display at all times during a trial.

Dark adaption goggles were worn for 10-15 min. prior to each recording session. The experiment was conducted in an electrically shielded and partially sound-attenuated room, with intercom contact between S and experimenter (E).

Stimulus presentation was made random by means of an LVE Probability Gate set at fifty-per-cent (50% probability of an output for every input) so both relevant and irrelevant stimuli had an equal chance of being presented. Thus, it was impossible for S to predict which stimulus would be presented on any given trial.

In the "count response condition" S had to keep track of the number of relevant flashes presented because he was required to press a key once he had counted 30 presentations, and his report was compared to the actual number of presentations recorded by an electro-mechanical counter. In the "RT response condition" S was required to make a response to every

relevant presentation by releasing a microswitch key within 350 msec. after onset of the stimulus, otherwise a click was presented through a loudspeaker informing him of a miss. Both total responses and misses were recorded by electro-mechanical counters, but no record of actual reaction times was obtained. These measures were obtained to insure attention to the relevant stimulus during the entire trial and were not treated as dependent variables.

The dependent variable was the averaged cortical response evoked by the flashes. These responses were recorded from the occiput (2.5 cm. above the inion on the midline) by means of a gold-plated scalp electrode, with a reference electrode fixed to the right ear lobe. Resistance between these two poles was reduced below 10 K ohms.

Response signals were amplified by a Grass 7P5A Polygraph Pre-amplifier and a 7 DAC Amplifier, and then fed into a Fabri-Tek Instruments 1062 Instrument Computer. Low and high frequency polygraph filters were set at 1 and 35 Hz respectively. Cortical activity was monitored by polygraph pen recordings and a Hewlett-Packard 141 Oscilloscope. Similarly, the actual presentation of the stimuli was duplicated outside S's room on an LVE Monitor Screen, so that E could see what S was responding to at any moment. Extraneous noise from the equipment was masked by a 901B Grason-Stadler Noise Generator, which flooded S's room with "white" noise during the experimental trials.

The computer was set to record and summate VERs occurring during the 512 and 1024 msec. following the presentation of stimuli for the fast and slow rate respectively. The gradual summation of VERs was monitored on an RM 504 Tektronix Oscilloscope in order to detect any extraneous signal that could have contaminated the records. Averages of evoked responses for each condition were permanently recorded on graph paper with a Hewlett-Packard 7035B X-Y Recorder.

Evoked potentials to relevant and irrelevant stimuli were fed into different channels in the computer by means of a relay. Leads from the relay to the computer channels were switched (i.e., a "relevant" channel became "irrelevant" and vice versa) after the second replication for all Ss, so that any undetected channel bias in the computer influenced VERs to relevant and irrelevant stimuli equally.

Evoked potentials to both stimuli within each Problem, when both relevant and irrelevant, were obtained by this procedure. By subtracting the "irrelevant" from the "relevant" VERs to a given stimulus (which was done electronically by the computer) it was also possible to obtain a graphic record of this difference which reflected the effects of selective attention.

Records obtained in the four replications were superimposed by visual inspection and a common baseline was calculated (average voltage level at trace onset). All measurements were made from this baseline (Harter & Salmon, 1971).

Results

Results included in this report represent one-half of the total data obtained in the experiment. Each Problem, as stated in the Method section, consisted of two light stimuli which were made relevant and irrelevant in each experimental session. Cortical responses to both stimuli in every Problem were found to follow similar trends when they were relevant and also when they were irrelevant, that being the reason why only one member of the pair was chosen for the statistical analyses.

Cortical Responses

Although averaged VERs for all stimuli differed in general waveform and amplitude due to the different dimensions they represented (i.e., color, shape, orientation), and amount of light they allowed the retina to be stimulated by (e.g., a square stimulated a larger area than a single bar), they all showed a consistent similarity (Figure 1): within each stimulus, an enhancement of a positive (downward) deflection between 290-340 msec. was observed when such stimulus was attended. When it was not attended, this positive component at such latency was either significantly reduced, non-existent, or in some cases negative. Similarly, a negative-going deflection with a latency of 220-250 msec. was also enhanced, although not as greatly, by the relevant stimulus. The relevant stimulus in all cases produced, then, not so much an overall enhancement of the cortical response,

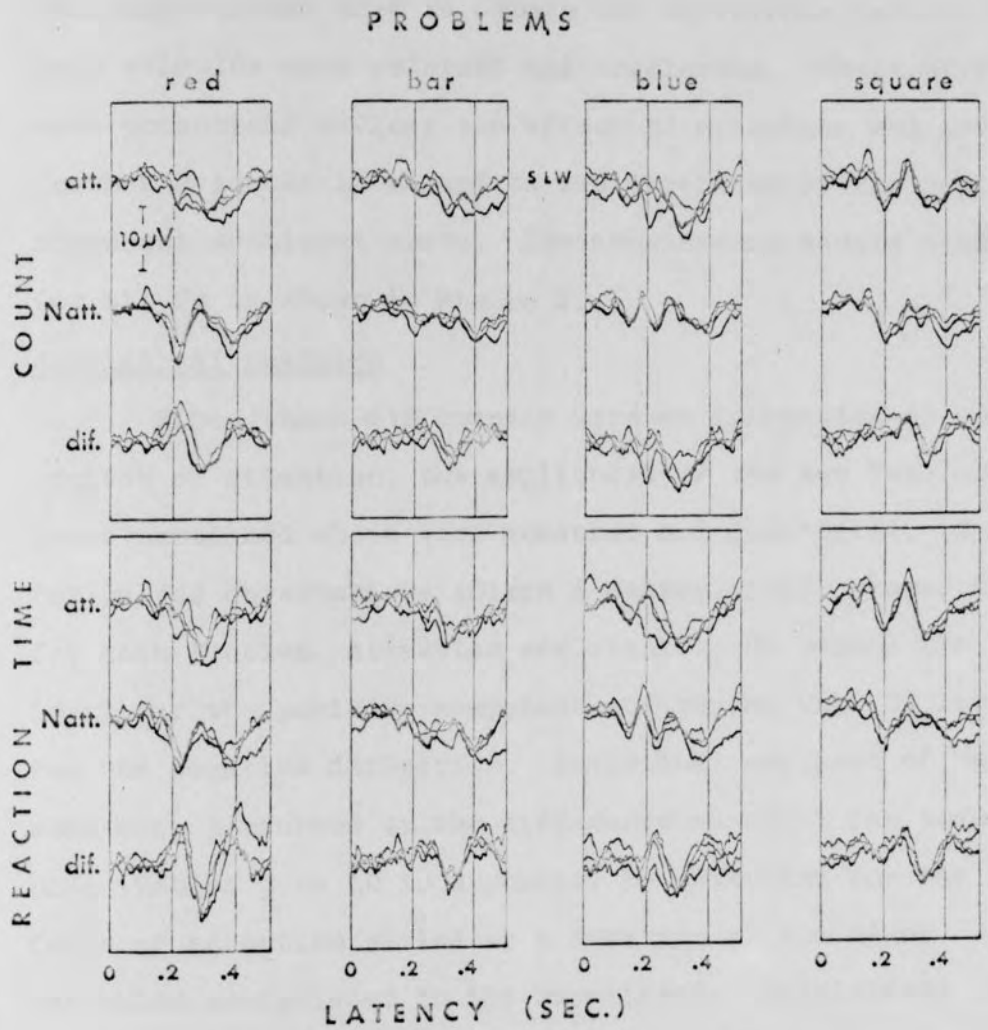


Fig. 1. Superimposition of averaged VERs obtained under the two response conditions at the fast rate. The two top traces for both Count and RT correspond to VERs elicited by the same stimulus when it was attended (att.) and when it was not attended (Natt.). The third trace shows the difference (dif.) between these two VERs, as obtained by the computer. Negativity up.

as an increase in the amplitude of particular components. The computer was used to obtain the difference between VERs to a stimulus when relevant and irrelevant. These difference potentials reflect the effect of attention and provide further evidence in regard to the direction of the amplitude increment mentioned above. Its consistency across conditions for all Ss is shown in Figure 2.

Statistical Analyses

Since these differences were an indication of the direction of attention, the amplitudes of the two late components mentioned above were measured and quantified. A *t* test for paired observations (Dixon & Massey, 1957) showed that, for each Problem, attention was significant beyond the .005 level for the positive component and beyond the .05 level for the negative deflection. Individual analyses of variance were performed on the difference measures for each Problem (Tables 3 to 10 in Appendix) to determine how the effects of attention varied as a function of the other variables manipulated in the experiment. Significant differences between Ss were obtained for Problem One at both latencies ($p<.01$), and Problem Four at the earlier one ($p<.01$). These two Problems were evaluated by Ss to be the easiest and hardest, respectively. The last Problem was particularly difficult because of the similarity of the two stimuli, a square and a circle of approximately the same area, which made them fall almost on the same retinal points.

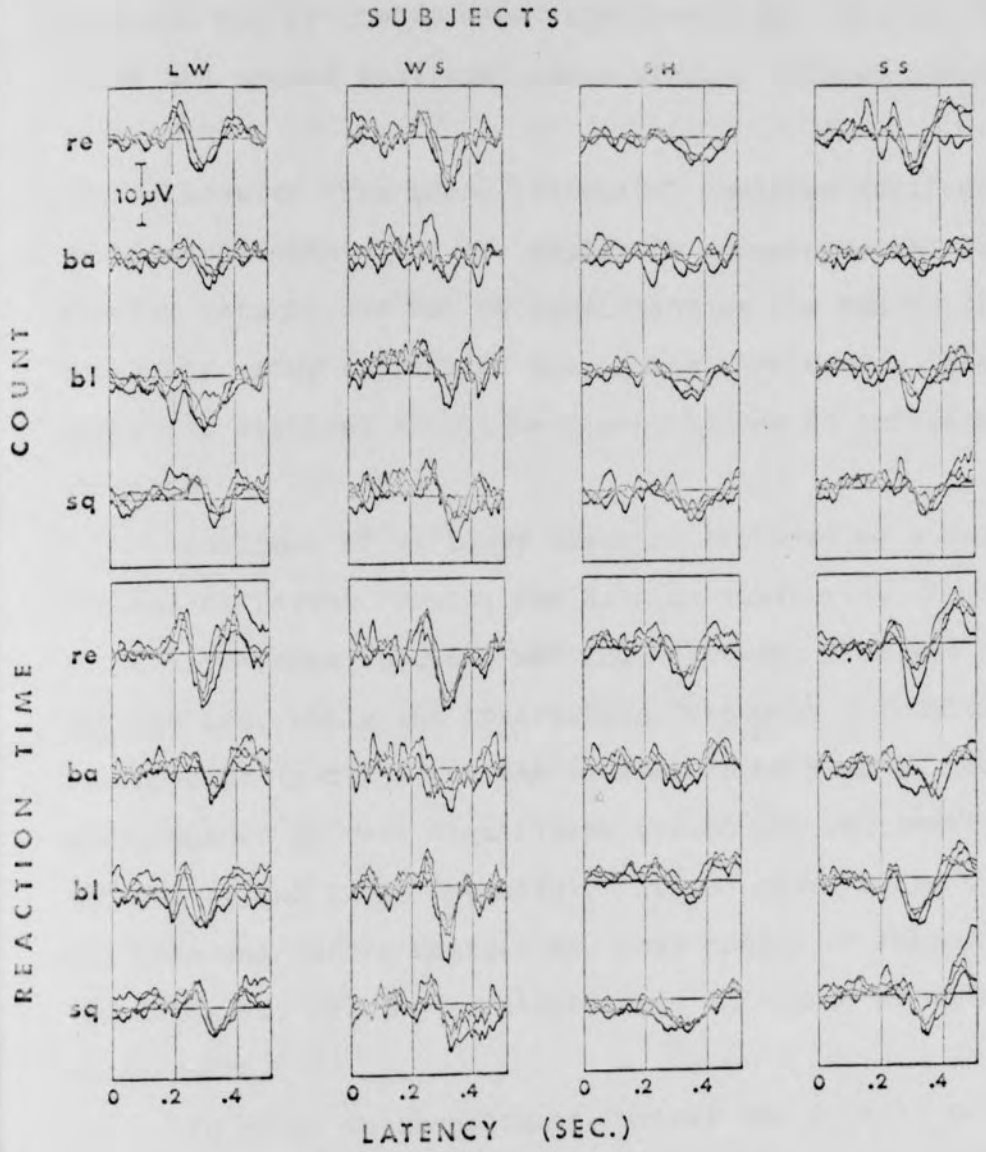


Fig. 2. Differences between VERs to the same stimulus when attended and not attended for each S over all Problems. Data shown correspond to superimposition of four replications for both response conditions at the fast rate.

Response and frequency were significant (p .01) for the third and second Problems, respectively, both at the earlier latency.

Results from these individual analyses ratified the earlier statement that the amplitude enhancement at the shorter latency was not as consistent as the one at the LPC. Similarly, they emphasized the logical assumption that the different Problems should have constituted an influential variable.

Analyses of variance treating Problems as a variable yielded different results for both measurements. A significant difference ($p < .01$) was found between Problems only for the LPC, while the interaction Frequency x Problems was significant ($p < .05$) for the shorter latency only. For both measurements Ss were significant beyond the .01 level (Tables 11 and 12 in Appendix). It was interesting to find, and this was rather unexpected, that manner of responding (counting vs. RT) had no significant influence on either measurement.

In order to investigate further the effects of these variables on the total variance, Omega Squares were calculated (Table 13 in Appendix) so that an objective indicant of the amount of variance accounted for by each one of these factors could be obtained. Results from these operations ratified the previous findings, especially that response and frequency effects were almost totally negligible.

Discussion

The Late Positive Component

Results from this study have shown that the same light stimulus evokes a different occipital response when it is attended than when it is not attended. The direction of attention was consistently indicated by the enhancement of a negative component at a latency of 220-250 msec. and an even more pronounced increase of a late positive component between 290 and 340 msec. Although there seemed to be a trend in this direction, a marked overall increase in amplitude of the VERs when the stimulus was relevant was not observed.

The lack of significant interactions between the effects of attention and both mode of response and frequency of stimulation reflects the consistency of the VERs obtained under these different conditions. Of particular importance was the finding that response mode *per se* had very little influence on evoked potentials; that is, there were no significant differences between VERs recorded under the count and RT conditions.

From this general overview of the findings it can be concluded that attention to a stimulus is reflected in an enhancement of late VER components, principally a positive deflection occurring between 290 and 340 msec. after onset of stimulation. This conclusion agrees with that of Donchin & Cohen (1967) in that visual search *per se* or transient changes in arousal are not the crucial variables for VER

amplitude differences. Rather, selective attention or the relevance assigned to a stimulus by S seem to be the real reason for the differences found in these late components.

Findings by Ritter & Vaughan (1969) provide additional support for this position. In their study, detected signals evoked a bigger response than non-detected signals, the magnitude of the increase being mainly in the LPC. It was concluded that this late component appeared to be a correlate of central processes for the cognitive evaluation of stimulus significance.

Of particular relevance for the present experiment was their finding that the LPC was not representing a motor potential from the key press required for the signal detection. In one condition Ss were instructed to withhold their response to the detected signals for at least one second after detection; and in another situation they were required to respond to the non-signals while ignoring the signals. They reported comparable LPCs elicited by the detected signals in both cases. The two conditions stated above are similar to those under which the attention study reported in this thesis was conducted, and results from both experiments indicate that motor responses required in these conditions had insignificant influences on the response evoked by the relevant stimulus.

Expectancy and the LPC

In a study performed by Sutton, et al. (1965a), in which they used the classical pairing of signal- and test-stimuli (Walter, 1964b), it was found that, as they varied the degree of certainty about the occurrence of one of two test stimuli (a light or a click) to which S had to make a reaction, the amplitude of the LPC also varied. This late component increased in amplitude as the degree of certainty decreased, and acquired the greatest enhancement when there were absolutely no clues as to the occurrence of the second stimulus; that is, when all the information required for the response was supplied by the stimulus itself.

The present study seems to agree entirely with the findings reported by Sutton, et al. The randomness of the stimulus presentation made it impossible for Ss to anticipate which of the two stimuli would be presented next, therefore all task-relevant information was provided by the attended stimulus itself.

Sutton, et al. did not record the ongoing cortical activity during the S_1-S_2 interval. This measure would have provided an indication of the extent to which the CNV was associated with different degrees of expectancy; and furthermore, in what ways, if any, it influenced the cortical response to the relevant stimulus.

Cohen & Walter (1966) studied these relationships to a certain extent. A signal click was paired to either a

blank flash, different geometric figures, or a single geometric shape. After several presentations, the expectancy waves for the blanks or the repeated figures were very small compared to those for the different shapes, which Ss had to recognize. It thus appeared that the degree of information to be expected from the different S_2s (little or none from the blank flashes and single figure, much more from the changing shapes) had a correlate in this negative deflection.

It should be expected, then, that since degree of information to be obtained from the S_2 caused an increase in CNV (Cohen & Walter, 1966), and information provided by the S_2 produced an enhancement of the LPC (Sutton, et al., 1965a), a high CNV must correlate with a high LPC. Cohen & Walter (1966) found that this was true in some cases, but that in certain conditions an LPC enhancement was obtained in cortical responses to informative stimuli except when CNV was present, adding that "The positive deflection may last for a second or more and is not apparently related to the amplitude or occurrence of the CNV." (Cohen & Walter, 1966, pp. 195). These conflicting results make it difficult to assign CNV with predictive functions as far as the LPC is concerned. Further evidence is provided by this paper's results.

The fact that presentation of relevant and irrelevant stimuli was randomized, plus the fact that all inter stimulus intervals (ISI) were fixed for a given condition, provided

S with absolutely no clues as to the presentation of one particular stimulus during the entire trial. Preparatory states, or expectancy, then, should have been constant throughout the trial for the above mentioned reasons. Provided that this was the case, as the experimental setup seems to have warranted, then VERs to both stimuli should have shown similar signs of CNV influence. In other words, having kept all other variables constant, any discrepancy between the two VERs must have been due to S's differential attitude towards the two stimuli, presumably attending to one while ignoring the other, as discussed below.

These conclusions are in conflict with those of Näätänen's for a similar experiment (his second) in which two modalities, vision and audition, were involved (Näätänen, 1967). He concluded that "changes in the direction of attention probably have no influence on evoked potentials when the peripheral factors are properly controlled. This indicates that activation and alertness must be the crucial factors in producing evoked potential enhancement attributed to selective attention in related studies on audition conducted in humans" (Näätänen, 1967, pp. 117), and that the same inference could be extended to the visual modality if such peripheral factors were properly controlled. It was suggested, then, that these factors were responsible for the significant differences found between relevant and irrelevant flashes, which were mainly reflected in an enhancement of the LPC for the relevant stimulus.

Näätänen found bases for his assertion that activation, and not attention, was responsible for VER differences on his findings in the audition experiment, which provided no significant differences whether attended or not. However, a visual comparison of evoked responses by relevant and irrelevant clicks showed that neither response had an LPC, which suggests that clicks may have never provided relevant information to S; that is, the task of detecting the weaker clicks may have become too easy, thus resulting in an actual loss in attention comparable to the condition in which Ss did not have to attend to them. This interpretation is consistent to that of Naatanen for identical results in a similar (his third) experiment (Näätänen, 1967, pp. 166).

In connection with a similar case, Ritter & Vaughan (1969) suggested that an easy discrimination task results at first in LPCs in cortical responses to both stimuli, but as soon as the task becomes routinized the LPC disappears in both responses. Similar interpretations could be applied to Naatanen's non-significant differences between relevant and irrelevant clicks.

Peripheral influences within the visual modality, suggested by Näätänen (1967) as the reason for differences between VERs to attended and non-attended stimuli, were ruled out in the present study. Subjects were emphatically asked to keep their line of vision fixated at the reference point on the center of the projection screen, and were told to

withhold any extraneous reactions (e.g., movements, eye blinking, coughing, etc.) until the trial was over. This was found not difficult to do because of the short length of the trials (32.7 and 64.5 sec. for the fast and slow rate, respectively).

A final point in comparing these and Näätänen's findings concerns his assertion that differential preparatory states prior to and at the presentation of relevant and irrelevant stimuli are the real causes of enhancement of evoked potentials to the stimulus S is instructed to attend. He further concluded that the slow CNV was the indicant of these states, since in regular alternations of relevant and irrelevant stimuli these waves were much higher (more negative) before the presentation of a relevant stimulus (dropping after its presentation and continuing steadily for about 350-400 msec.) than before an irrelevant signal, thus biasing the evoked response precisely in the direction of positivity.

Findings from the present experiment are in disagreement with Näätänen's conclusions. As stated earlier, stimulus presentation was random, therefore any CNV activity, if present, was statistically identical for both relevant and irrelevant stimuli, and could not have reliably predicted an LPC enhancement in VERs to relevant stimuli.

The LPC and Theoretical Positions

As data from the present and related studies have suggested, attention to a stimulus seems to be reflected in an enhancement of a positive-going deflection at or around 300 msec. Different variables (i.e., expectancy, peripheral factors, etc.) that have been suggested as possible reasons for this amplitude increase have been ruled out, at least for experiments in which randomness of stimulus presentation is achieved. However, the question concerning the causes of the LPC has not been answered. The presence of a gating mechanism like that of Hernández-Peón has been ruled out by the fact that only one modality was used in the present experiment. Eason, et al. (1969) suggested the operation of an active inhibitory neural process which sometimes attenuated the perception of irrelevant stimuli to the point that S could no longer detect them. This perceptual decrease of the physical intensity of the stimulus evoked a much reduced cortical potential, which finally disappeared when S could no longer "see" the flashes. This, however, also proved not to be the case. Subjects never reported total suppression or significant attenuation of irrelevant signals. This fact was supported by the lack of consistent differences in overall amplitude between VERs to relevant and irrelevant signals.

If the foregoing factors are also ruled out, the next conclusion has to be, then, that the differences in evoked

responses to physically identical relevant and irrelevant stimuli may be due to the manner in which the organism responds to them once they have been perceived. One possible explanation could be that pupillary size increases upon detection of relevant stimuli permit a longer exposure, thus provoking a second stimulation with a longer latency which would explain the existence of the LPC. Hess & Polt (1960) reported that pupil size increased according to the interest value of the stimulus. They recorded no cortical responses, therefore the effects of such a longer exposure on VER latency cannot be assessed until more data are available.

Another point of view is offered by Sokolov (1963), who suggested that when S is instructed to attend to stimulus A and ignore signal B, it is possible that a mental pattern or "template" for rejection comes to work in this situation. Every time signal B is presented it matches the template, which presumably works at a lower level, and then is allowed to be assimilated without any further analysis. When signal A is presented, however, it does not match the rejection pattern and is quickly re-evaluated as to its significance. This re-evaluation might then be reflected in an enhancement of a later component, possibly positive-going (Ritter & Vaughan, 1969).

An interpretation parallel to the one just discussed is that the task to be performed by S may be the real reason for the late positivity. In all the experiments dealing

with attention, relevance of a stimulus is usually signified by a response (counting, key press, reaction time, etc.) that S has to emit every time such signal is presented. Conversely, an irrelevant stimulus is to be ignored, consequently no response is ever required. Throughout the experimental session S has to be ready to react to the relevant stimulus in the appropriate way, while simultaneously withholding this reaction when the irrelevant signal is presented.

It could be postulated, then, that the mental release (not the actual motor action, since some responses, like mental counting, are not motor) of the reaction to the relevant stimulus might provoke a late excitation of the cortex, thus causing the LPC enhancement (Karlin, 1970). When the irrelevant stimulus is presented the reaction is withheld, therefore the LPC is absent.

These theoretical positions have provided several alternatives for the existence of an LPC enhancement in cortical responses to relevant stimuli. Although their approaches are somewhat different, the common factor in them is the conclusion that such an increment in amplitude is present only when S is discriminatorily reacting to a relevant stimulus, while simultaneously ignoring an irrelevant signal. Results from the study reported in this paper agree with the conclusion expressed above, providing further support for the selective attention position and yielding supportive evidence against the anticipatory state hypothesis.

Summary

The purpose of the present study was to investigate the influences of attention on the visually evoked cortical response (VER) when peripheral factors and preparatory states are accounted for. This was accomplished by presenting a random series of relevant and irrelevant stimuli at exactly the same rate, so that there were absolutely no clues as to the presentation of the relevant stimulus. Peripheral influences were kept at a minimum by instructing Ss to keep their fixation of a reference point on the center of the projection screen for the length of the trial and to withhold any reaction that could contaminate the record. The short duration of the trials facilitated this accomplishment. Two response conditions (counting the number of relevant signals or making a key release in response to them) and two frequencies of presentation (520 and 1030 msec.) were manipulated in order to investigate their effects on the cortical responses.

A significant increase in amplitude, with latencies of 220-250, and 290-340 msec., was observed when the stimulus was attended (responded to), as compared to responses for the same stimulus when it was not attended (not responded to). It was also found that the different response conditions and the two rates of presentation did not affect the cortical response, suggesting that the enhancement of the VER to the relevant stimulus was not caused by the motor response required in some conditions.

Two hypotheses, one concerning selective attention, and the other postulating different preparatory and/or arousal states as the reason for VER enhancement were compared against the data obtained in this study. It was concluded that selective attention to a particular stimulus accounts for the increase in amplitude of the cortical response, as indicated by the LPC enhancement found in VERs to relevant stimuli. Furthermore, this enhancement did not seem to be a reflection of expectancy on the part of S, since he never could predict when a relevant stimulus would be presented.

References

Bergamini, L., Bergamasco, B., & Mombelli, A. Étude sur les élément qui influent la variabilité des réponses corticales évoquées visuelles chez l'homme. Deuxième Symposium Mnemotron, Paris, 1964. Electrodiagnostic-Electrothérapie, 1966 (a), 1, 22-33. Cited by Bergamini, L., & Bergamasco, B. Cortical evoked potentials in man. Springfield, Ill.: Charles C. Thomas, 1967. P. 38.

Bergamini, L., Bergamasco, B., & Mombelli, A. Variations du potentiél évoqué visuel chez l'homme provoquées par les modifications du diamètre pupillaire et de l'état d'activation corticale, avec référence particulière aux phénomènes d'habituation, d'attention et de distraction. Journal Physiologie, Paris, 1966 (b), 58, 671-685. Cited by Bergamini, L., & Bergamasco, B. Cortical evoked potentials in man. Springfield, Ill.: Charles C. Thomas, 1967. P. 39.

Cigánek, L. Variability of the human visual evoked response: normative data. Electroencephalography and clinical Neurophysiology, 1969, 27 (1), 35-42.

Cohen, J., & Walter, W. G. The interaction of responses in the brain to semantic stimuli. Psychophysiology, 1966, 2, 187-196.

Davis, H. Enhancement of evoked cortical potentials in humans related to a task requiring a decision. Science, 1964, 145, 182-183.

Dixon, W. S., & Massey, F. J., Jr. Introduction to statistical analysis. McGraw-Hill: New York, 1957.

Donchin, E., & Cohen, L. Averaged evoked potentials and intramodality selective attention. Electroencephalography and clinical Neurophysiology, 1967, 22 (6), 537-546.

Donchin, E., & Cohen, L. Anticipation of relevant stimuli and evoked potentials: a reply to Naatanen. Perceptual and Motor Skills, 1969, 29 (1), 115-117.

Donchin, E., & Cohen, L. Further reply to Naatanen. Perceptual and Motor Skills, 1969, 29 (1), 270.

Donchin, E., & Smith, D. B. D. The CNV and P300--two sides of the same coin. Paper given at the annual meeting of the American EEG Society, San Francisco, 1968.

Eason, R. G., Harter, M. R., & White, C. T. Effects of attention and arousal on visually evoked cortical potentials and reaction time in man. Physiology and Behavior, 1969, 4, 283-289.

Fernández-Guardiola, A., Harmony, T., & Roldan, E. Modulation of visual input by pupillary mechanisms. Electroencephalography and clinical Neurophysiology, 1964, 16, 259-268.

García-Austt, E., Bogacz, J., & Venzulli, A. Effects of attention and inattention upon visual evoked response. Electroencephalography and clinical Neurophysiology, 1964, 17, 136-143.

Gilden, L., Vaughan, H. G., Jr., & Costa, L. D. Summated human EEG potentials with voluntary movement. Electroencephalography and clinical Neurophysiology, 1966, 20, 433-438.

Gross, M. M., Begleiter, A., Tobin, M., & Kissin, B. Auditory evoked response comparison during counting clicks and reading. Electroencephalography and clinical Neurophysiology, 1965, 18, 451-454.

Groves, P. M., & Eason, R. G. Visually evoked cortical potentials from different cortical regions in humans. Psychonomic Science, 1967, 9 (1), 19-20.

Haider, M., Spong, P., & Lindsley, D. B. Attention, Vigilance, and evoked cortical potentials in humans. Science, 1964, 145, 180-182.

Harter, M. R., & Salmon, L. E. Evoked cortical potentials to patterned light flashes: effects of ocular convergence and accommodation. Electroencephalography and clinical Neurophysiology, 1971 (in press).

Hernández-Peón, R., Scherrer, H., & Jouvet, M. Modification of electrical activity in the cochlear nucleus during "attention" in unanesthetized cats. Science, 1956, 123, 331-332.

Hess, E. H., & Polt, J. M. Pupil size as related to interest value of visual stimuli. Science, 1960, 132, 349-350.

Horn, G. Electrical activity of the cerebral cortex of unanesthetized cats during attentive behavior. Brain, 1960, 83, 57-76.

Jane, J. A., Smirnov, G. D., & Jasper, H. H. Effects of distraction upon simultaneous auditory and visual evoked potentials. Electroencephalography and clinical Neurophysiology, 1962, 14, 344-357.

Jonkman, E. J. The average cortical response to photic stimulation. N. V. Drukkerij Trio -'s - Gravenhage, 1967. P. 13.

Karlin, L. Cognition, preparation, and sensory-evoked potentials. Psychological Bulletin, 1970, 73 (2), 122-136.

Kirk, R. E. Experimental design: procedures for the behavioral sciences. Belmont, Calif.: Brooks/Cole, 1969.

Kopell, B. S., Wittner, W. K., & Warrick, G. L. The effects of stimulus differences, light intensity, and selective attention on the amplitude of the visual averaged evoked potential in man. Electroencephalography and clinical Neurophysiology, 1969, 26 (2), 619-622.

Kornhüber, H., & Deecke, L. Hirnpotential anderungen bei Wilkurbewegungen und passiven Bewegungen des Menschen: Bereitshafts potential und reafferent Potentiale. Pflügers Archiv fur die gesamte Physiologie, 1965, 284, 1-17. Cited by Karlin, 1970, Pp. 132-133.

Lindsley, D. B. Emotion. In S. S. Stevens (Ed.) Handbook of experimental psychology. New York: Wiley, 1951, 437-516.

Lindsley, D. B. Attention, consciousness, sleep and wakefulness. In Field, J., et al. (Eds.), Handbook of experimental psychology III. Washington, D. C.: American Physiologic Society, 1957, 1553-1593.

Low, M. D., Coats, A. C., Rettig, G. M., & McSherry, J. W. Anxiety, attentiveness-alertness: a phenomenological study of the CNV. Neurophysiologia, 1967, 5 (4), 379-384.

McAdam, D. W. Increases in CNS excitability during cortical slow potentials in man. Electroencephalography and clinical Neurophysiology, 1969, 26 (2), 216-219.

Melzack, R., & Burns, S. K. Neurophysiological effects of early sensory restriction. Expl. Neurol., 1965, 13, 163-175.

Mombelli, A., Bergamini, L., & Bergamasco, B. Studio su i potenziali evocati fotici nell'uomo. Nota III. Comportamento delle resposte evocate durante lo stato de attenzione e distrazione. Rivista Patologica Nervosa Mentale, 1964, 85, 582-588. Cited by Bergamini, L., & Bergamasco, B. Cortical evoked potentials in man. Springfield, Ill.: Charles C. Thomas, 1967. P. 39.

Morgan, C. T. Physiological psychology. (3rd. ed.) New York: McGraw-Hill, 1968.

Moruzzi, G., & Magoun, H. W. Brain stem reticular formation and activation of the EEG. Electroencephalography and clinical Neurophysiology, 1949, 1, 445-473.

Näätänen, R. Selective attention and evoked potentials. Annales Academiae Scientiarum Fennicae, 1967, 151, 226 pages.

Näätänen, R. Anticipation of relevant stimuli and evoked potentials: a comment on Donchin's and Cohen's "Averaged evoked potentials and intramodality selective attention". Perceptual and Motor Skills, 1969, 28 (2) 639-646.

Näätänen, R. Anticipation of relevant stimuli and evoked potentials: a reply to Donchin and Cohen. Perceptual and Motor Skills, 1969, 29 (1) 233-234.

Näätänen, R. Evoked potentials, EEG, and slow potential correlates of selective attention. Acta Psychologica, Amsterdam, 1970, 33, 178-192.

Naquet, R., Régis, H., Fischer-Williams, M., & Fernández-Guardiola, A. Variations in the responses evoked by light along the specific pathways. Brain, 1960, 83, 55-56.

Ritter, W., & Vaughan, H. Averaged evoked responses in vigilance and discrimination: a reassessment. Science, 1969, 164, 326-328.

Satterfield, J. H. Evoked cortical response enhancement and attention in man. A study of responses to auditory and shock stimuli. Electroencephalography and clinical Neurophysiology, 1965, 19, 470-475.

Shaw, J. A., & Thompson, R. F. Dependence of evoked cortical association responses on behavioral variables. Psychonomic Science, 1964, 1, 153-154 (a).

Shaw, J. A., & Thompson, R. F. Inverse relation between evoked cortical association responses and behavioral orienting to repeated auditory stimuli. Psychonomic Science, 1964, 1, 399-400 (b).

Spong, P., Haider, M., & Lindsley, D. B. Selective attentiveness and cortical evoked potentials to visual and auditory stimuli. Science, 1965, 148, 395-397.

Sutton, S., Braren, M., & Zubin, J. Evoked potential correlates of stimulus uncertainty. Science, 1965, 150, 1187-1188 (a).

Tecce, J. Contingent negative variation and individual differences. Archives of General Psychiatry, 1971, 24, 1-16.

Tecce, J., & Scheff, N. Attention reduction and suppressed direct-current potentials in the human brain. Science, 1969, 164, 331-333.

Thompson, R. F., Denny, D., & Smith, H. E. Cortical control of specific and nonspecific sensory projections to the cerebral cortex. Psychonomic Science, 1966, 4, 93-94.

Thompson, R. F., & Shaw, J. A. Behavioral correlates of evoked activity recorded from association areas of the cerebral cortex. Journal of Comparative and Physiological Psychology, 1965, 60, 329-339.

Vaughan, H. S., Jr., Costa, L. D., Gilden, L., & Schimmel, H. Identification of sensory and motor components of cerebral activity in simple reaction time tasks. Proceedings of the 73rd. Annual Convention of the American Psychological Association, 1965, 1, 179-180.

Vaughan, H. S., Jr., Costa, L. D., & Ritter, W. Topography of the human motor potential. Electroencephalography and clinical Neurophysiology, 1968, 25, 1-10.

Walter, W. G. Slow potential waves in the human brain associated with expectancy, attention and decision. Archiv fur Psychiatrie und Zeitschrift fur die gesamte Neurologie, 1964, 206, 309-322 (b).

Walter, W. G. Effects on anterior brain responses of an expected association between stimuli. Journal of Psychosomatic Research, 1965, 9, 45.

Walter, W. G., Cooper, R., Aldridge, V. J., McCallum, W. C., & Winter, A. L. Contingent negative variation: an electric sign of sensori-motor association and expectancy in the human brain. Nature, 1964, 203, 380-384 (c).

Wilkinson, R. T., & Morlock, H. C. Auditory evoked responses and reaction time. Electroencephalography and clinical Neurophysiology, 1967, 23, 50-56.

APPENDIX

TABLE 3

Variance Analysis of Difference Scores

Problem One: 220-250 msec. Latency

Source	SS	df	MS	F
Subjects	388.85	3	129.62	10.92*
Frequency	133.75	1	133.75	6.84
Response	9.77	1	9.77	2.4
Freq. x Resp.	2.84	1	2.84	
Freq. x Ss	58.67	3	19.56	
Resp. x Ss	12.22	3	4.07	
Freq. x Resp. x Ss	35.93	3	11.98	

* $p < .01$

TABLE 4

Variance Analysis of Difference Scores

Problem One: 290-340 msec. Latency

Source	SS	df	MS	F
Subjects	439.70	3	146.57	18.03*
Frequency	1.97	1	1.97	
Response	169.79	1	169.79	41.82*
Freq. x Resp.	.93	1	.93	
Freq. x Ss	30.23	3	10.08	
Resp. x Ss	12.18	3	4.06	
Freq. x Resp. x Ss	30.68	3	10.26	

* $p < .01$

TABLE 5

Variance Analysis of Difference Scores

Problem Two: 220-250 msec. Latency

Source	SS	df	MS	F
Subjects	84.28	3	28.09	1.98
Frequency	.47	1	.47	
Response	70.14	1	70.14	69.94*
Freq. x Resp.	16.00	1	16.00	2.31
Freq. x Ss	18.66	3	6.22	
Resp. x Ss	3.23	3	1.08	
Freq. x Resp. x Ss	20.76	3	6.92	

* $p < .01$

TABLE 5

Variance Analysis of Difference Scores

Problem Two: 220-250 msec. Latency

Source	SS	df	MS	F
Subjects	84.28	3	28.09	1.98
Frequency	.47	1	.47	
Response	70.14	1	70.14	69.94*
Freq. x Resp.	16.00	1	16.00	2.31
Freq. x Ss	18.66	3	6.22	
Resp. x Ss	3.23	3	1.08	
Freq. x Resp. x Ss	20.76	3	6.92	

* $p < .01$

TABLE 6

Variance Analysis of Difference Scores

Problem Two: 290-340 msec. Latency

Source	SS	df	MS	F
Subjects	33.10	3	11.04	1.11
Frequency	24.98	1	24.98	1.25
Response	.14	1	.14	
Freq. x Resp.	14.54	1	14.54	5.57
Freq. x Ss	59.99	3	19.96	
Resp. x Ss	21.40	3	7.13	
Freq. x Resp. x Ss	7.82	3	2.61	

TABLE 7

Variance Analysis of Difference Scores

Problem Three: 220-250 msec. Latency

Source	SS	df	MS	F
Subjects	253.46	3	84.49	3.19
Frequency	29.59	1	29.59	113.81*
Response	.02	1	.02	
Freq. x Resp.	12.10	1	12.10	
Freq. x Ss	.78	3	.26	
Resp. x Ss	103.30	3	34.43	
Freq. x Resp. x Ss	134.33	3	44.78	

* $p < .01$

TABLE 8

Variance Analysis of Difference Scores

Problem Three: 290-340 msec. Latency

Source	SS	df	MS	F
Subjects	386.20	3	128.73	2.85
Frequency	.78	1	.78	
Response	72.29	1	72.29	
Freq. x Resp.	8.99	1	8.99	
Freq. x Ss	47.48	3	15.83	
Resp. x Ss	304.95	3	101.65	
Freq. x Resp. x Ss	54.25	3	18.08	

TABLE 9

Variance Analysis of Difference Scores

Problem Four: 220-250 msec. Latency

Source	SS	df	MS	F
Subjects	297.59	3	99.20	8.72*
Frequency	2.26	1	2.26	
Response	8.28	1	8.28	
Freq. x Resp.	.01	1	.01	
Freq. x Ss	54.95	3	18.32	
Resp. x Ss	35.08	3	11.69	
Freq. x Resp. x Ss	12.41	3	4.14	

* $p < .01$

TABLE 10

Variance Analysis of Difference Scores

Problem Four: 290-340 msec. Latency

Source	SS	df	MS	F
Subjects	30.35	3	10.12	
Frequency	34.51	1	34.51	2.59
Response	65.94	1	65.94	4.35
Freq. x Resp.	3.07	1	3.07	
Freq. x Ss	39.99	3	13.33	
Resp. x Ss	45.51	3	15.17	
Freq. x Resp. x Ss	22.39	3	7.46	

TABLE 11

Overall Analysis of Variance: 220-250 msec. Latency

Source	SS	df	MS	F
Subjects	744.00	3	248.00	14.49**
Frequency	65.51	1	65.51	4.38
Response	18.05	1	18.05	
Problems	201.19	3	67.06	3.03
Freq. x Resp.	.36	1	.36	
Freq. x Prob.	100.56	3	33.52	4.17*
Resp. x Prob.	70.15	3	23.38	2.06
Freq. x Resp. x Prob.	30.73	3	10.24	
Freq. x Ss	60.81	3	20.27	
Resp. x Ss	54.48	3	18.16	
Prob. x Ss	280.13	9	31.12	
Freq. x Resp. x Ss	82.00	3	27.33	
Freq. x Prob. x Ss	72.26	9	8.03	
Resp. x Prob. x Ss	102.06	9	11.34	
Freq. x Resp. x Prob. x Ss	118.60	9	13.18	

* $p < .05$

** $p < .01$

TABLE 12

Overall Analysis of Variance: 290-340 msec. Latency

Source	SS	df	MS	F
Subjects	511.57	3	170.52	9.07*
Frequency	43.22	1	43.22	2.64
Response	225.37	1	225.37	3.98
Problems	1,356.16	3	452.05	10.77*
Freq. x Resp.	22.72	1	22.72	8.45
Freq. x Prob.	19.00	3	6.33	
Resp. x Prob.	82.78	3	27.59	1.59
Freq. x Resp. x Prob.	4.80	3	1.60	
Freq. x Ss	82.49	3	27.50	
Resp. x Ss	169.98	3	56.66	
Prob. x Ss	377.73	9	41.97	
Freq. x Resp. x Ss	8.06	3	2.69	
Freq. x Prob. x Ss	88.38	9	9.82	
Resp. x Prob. x Ss	213.91	9	23.77	
Freq. x Resp. x Prob. x Ss	113.96	9	12.66	

* $p < .01$

TABLE 13

AMOUNT OF VARIANCE ACCOUNTED FOR

SOURCE	220-250	290-340
Subjects	34%	14%
Problems	5%	37%
Response	0	1%
Frequency	2%	0
Freq. x Prob.	0	4%